EUV lithography: today and tomorrow

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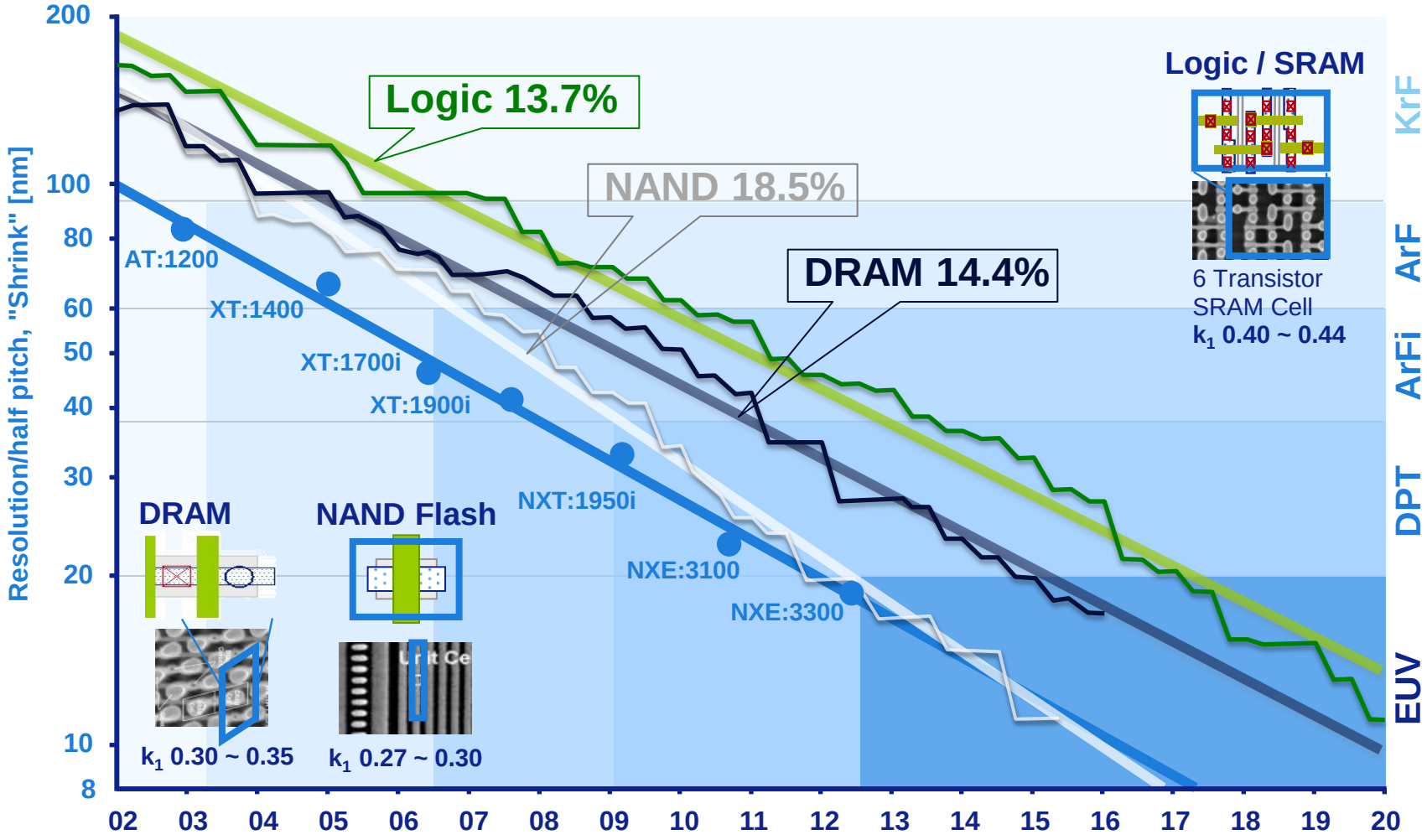
Dublin, October 2012

Industry roadmap towards < 10 nm resolution

Lithography supports shrink roadmap



* Note: Process development
1.5 ~ 2 years in advance updated 8/11

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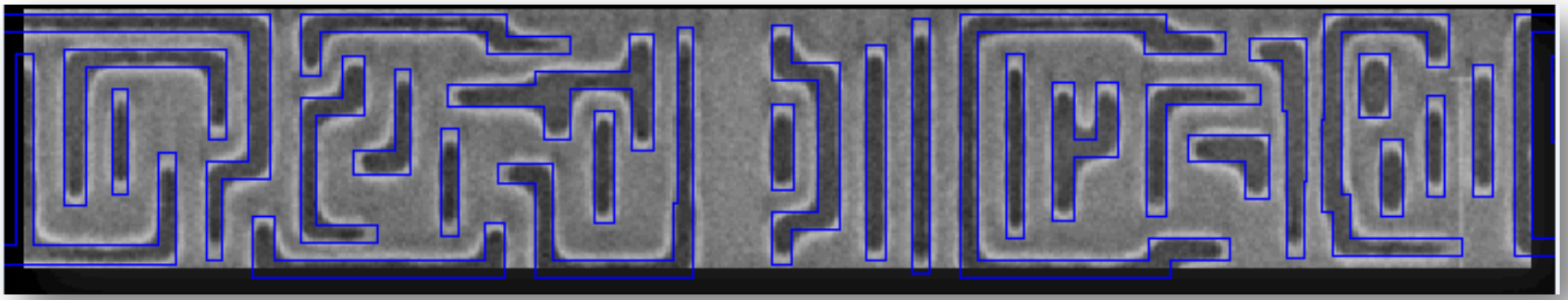
EUV enables 14nm node with large UDOF



14nm node ARM M1 clip without OPC, 46nm minimum pitch, exposed on an NXE:3300B with conventional illumination

	EUV	ArFi
	Single exposure	Double patterning (LELE)
Best HV focus difference	<10nm	up to 60nm
Usable depth of focus	>100nm	50nm

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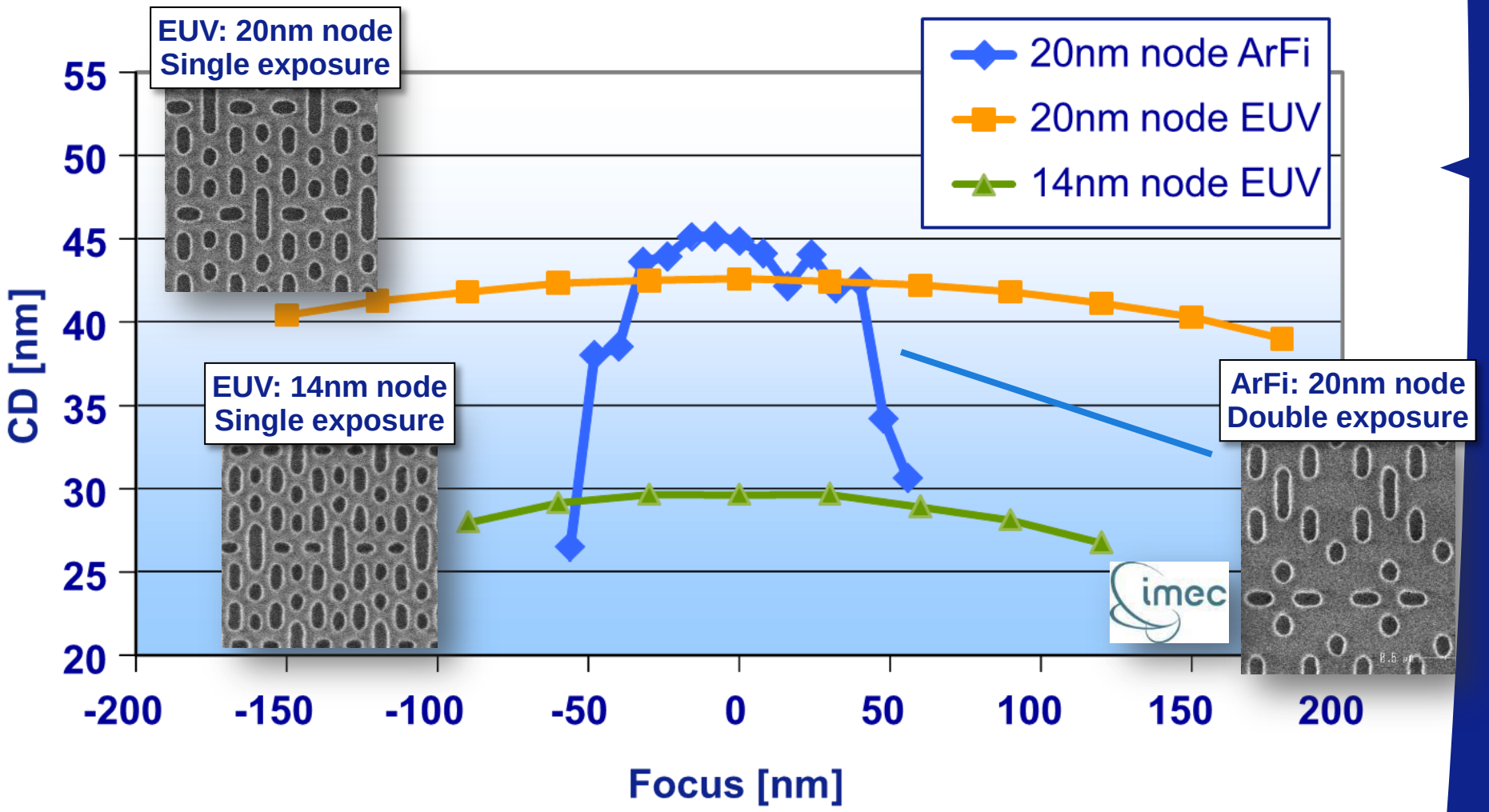
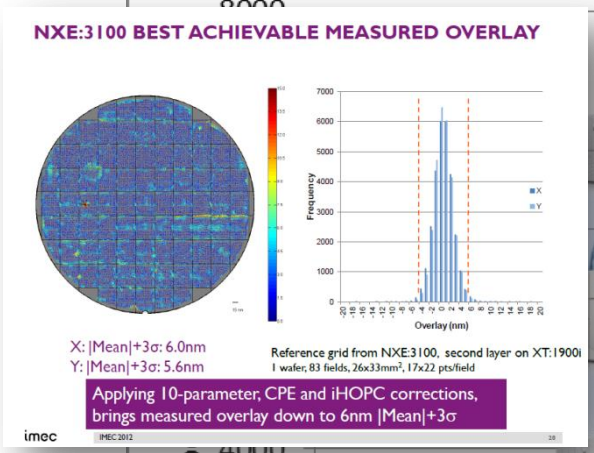
Large process windows measured on the 3100

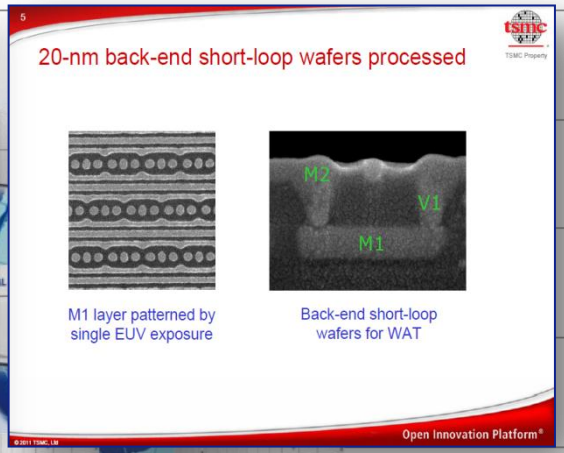
Down to 14nm node SRAM M1 layer

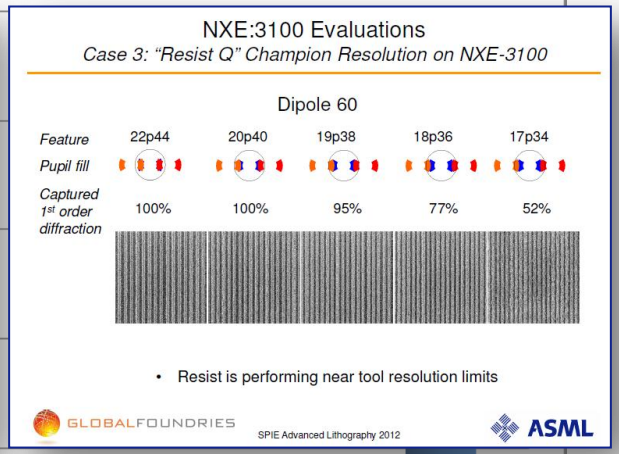


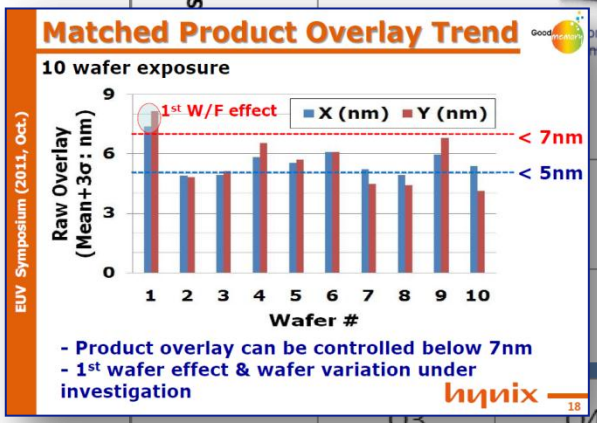
The NXE:3100 has exposed >23000 wafers

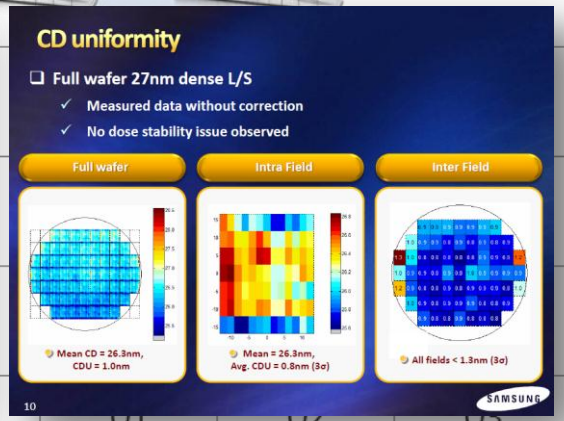
Increasing output per quarter

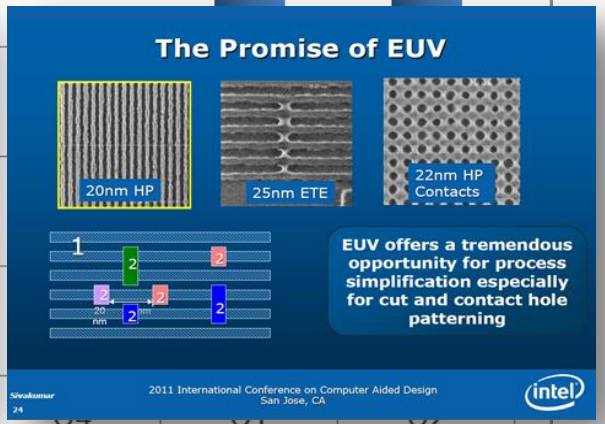






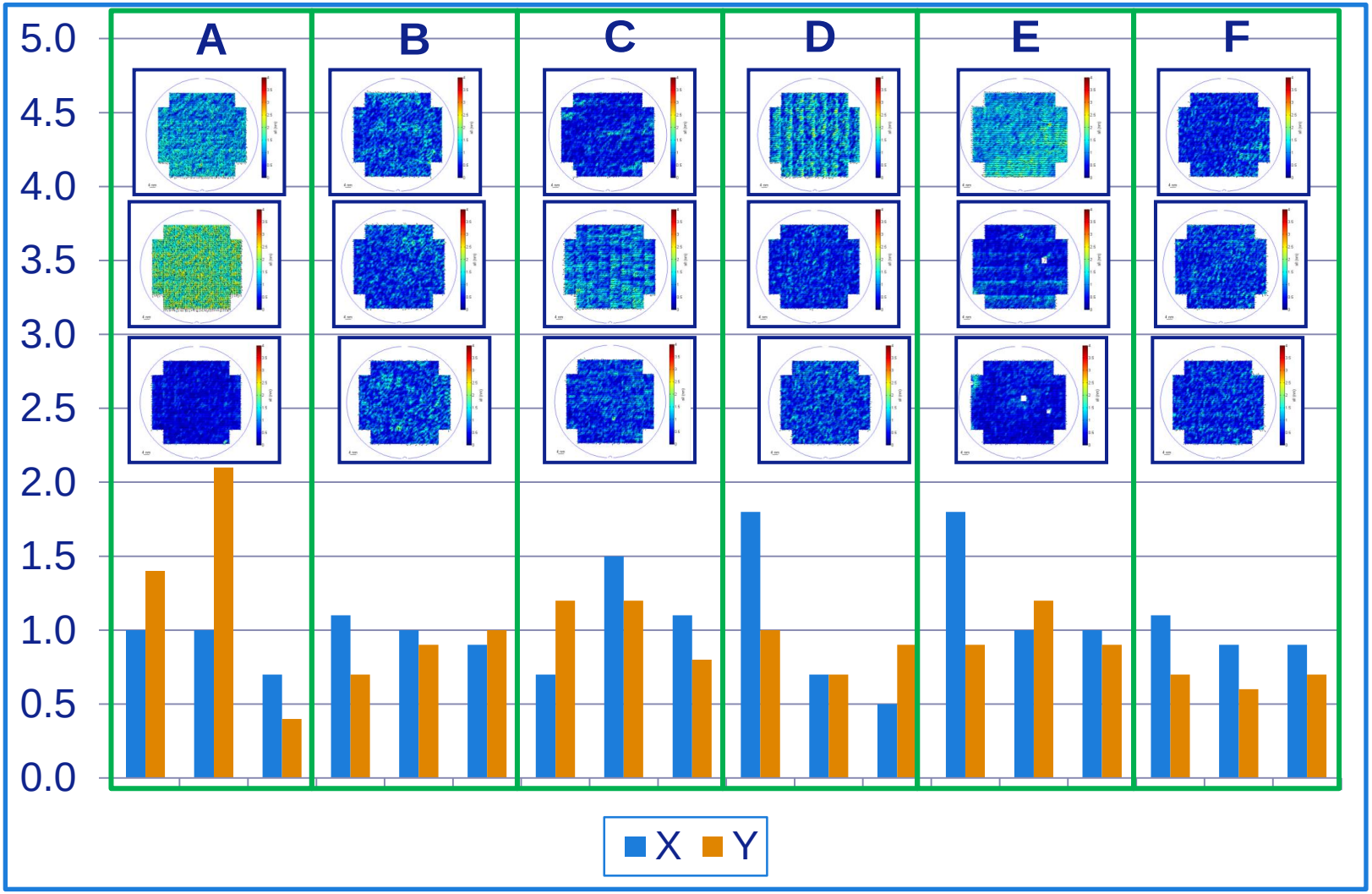






NXE:3100: consistent good overlay on all tools

Single Chuck Overlay less than ~2nm



All numbers are (X,Y) SCO results using ASML standard test method
SCO = single chuck overlay

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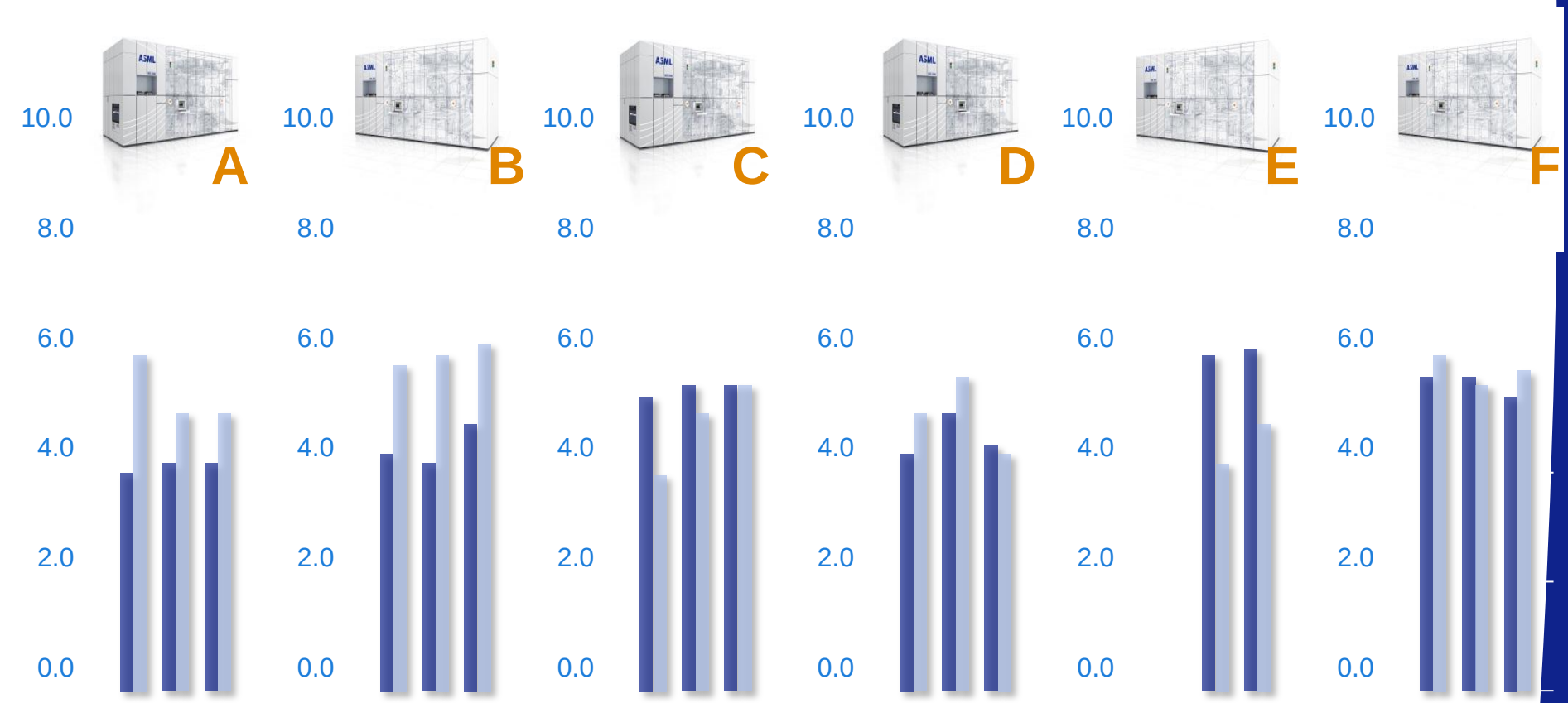
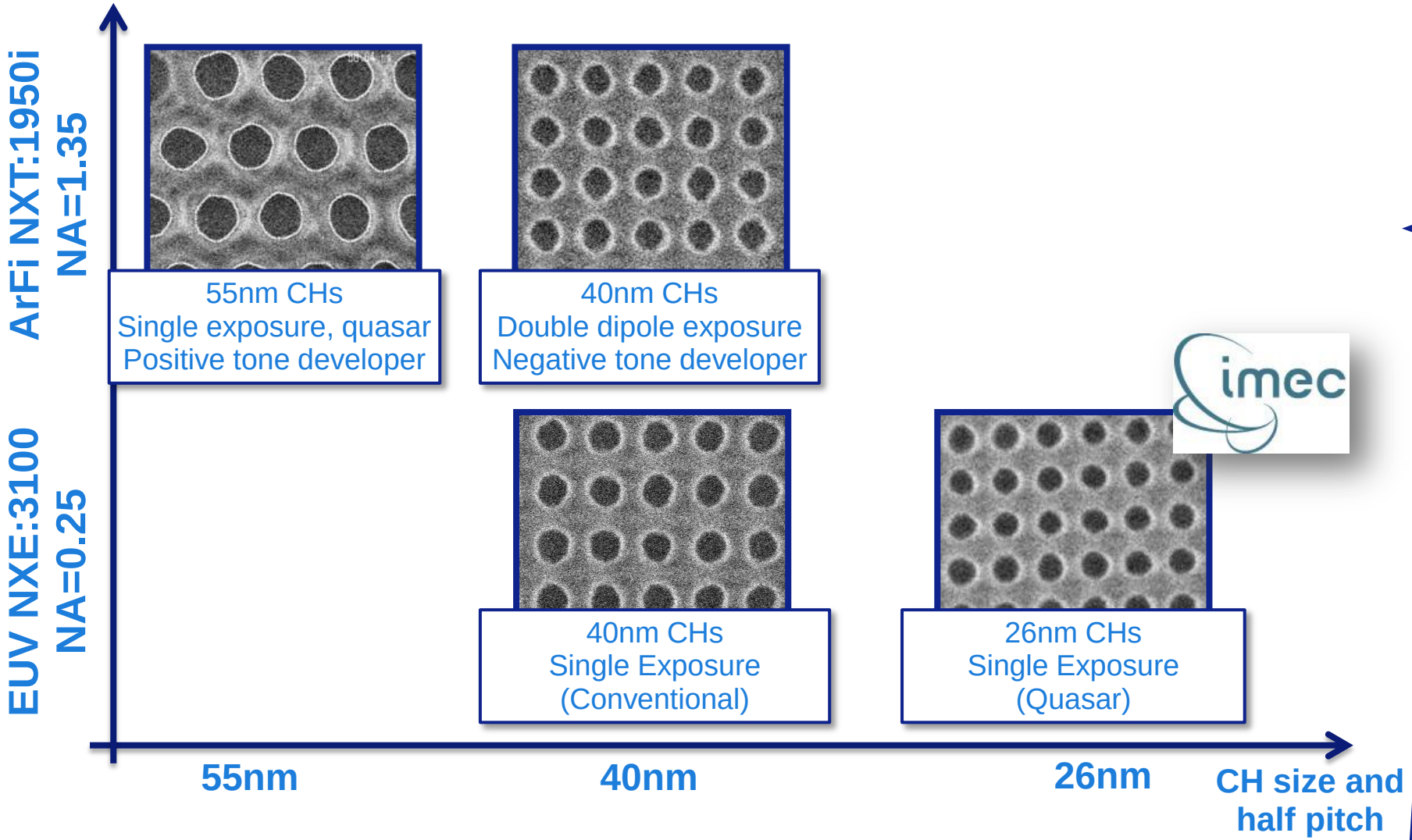
NXE:3100: consistent good overlay on all tools

Matched Machine Overlay ~6 nm



All numbers are (X,Y) matched machine overlay results to an ArF reference wafer using ASML standard test method

Dense CH imaging down to 26nm on NXE:3100



See presentation Eelco van Setten (ASML)

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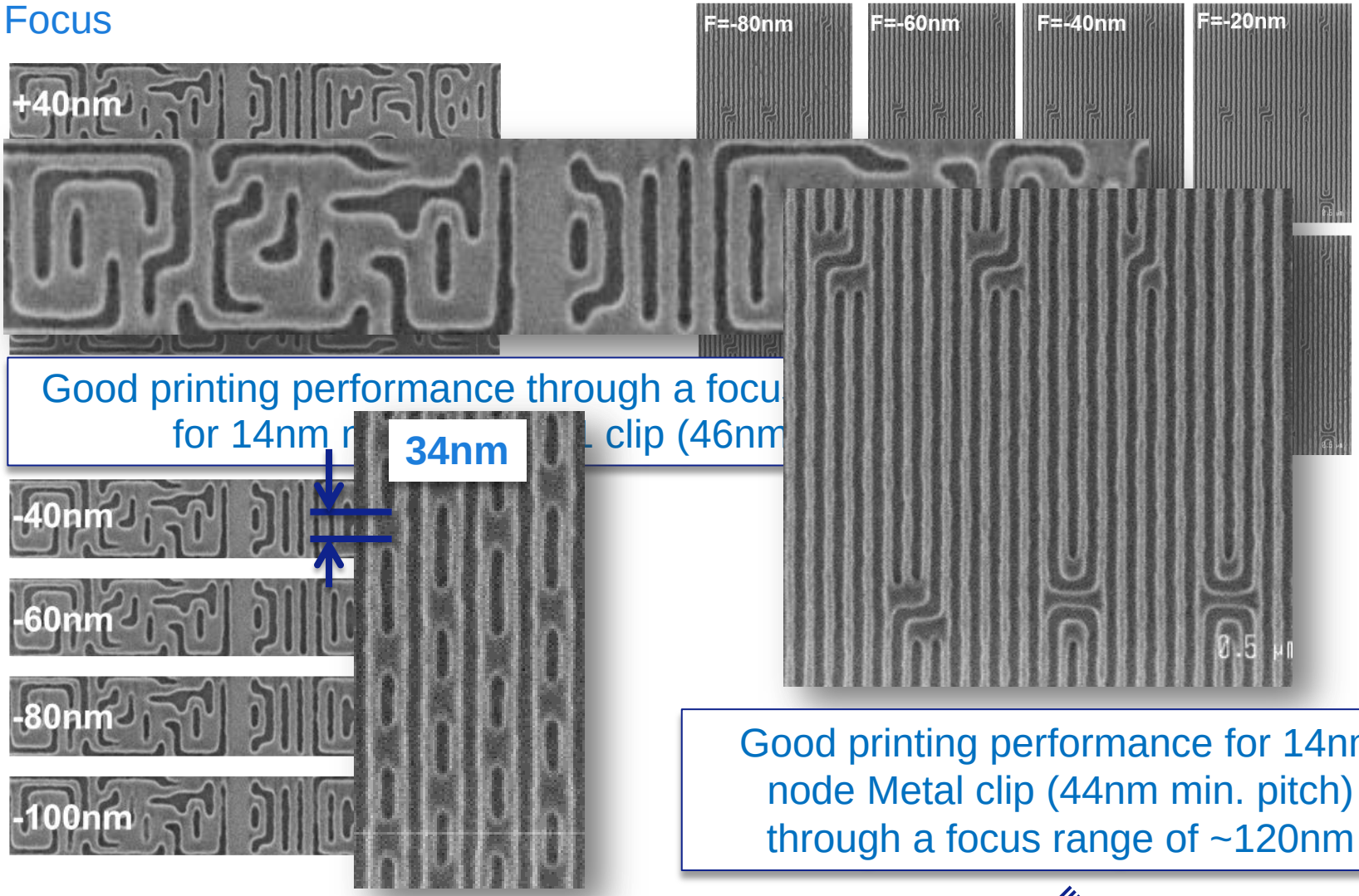
Single exposure 14nm node metal 1 features

Focus



Good printing performance for 14nm node Metal clip (44nm min. pitch) through a focus range of ~120nm

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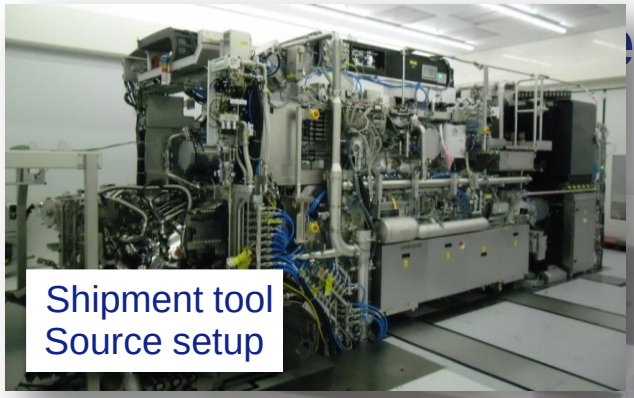
Shipment tool
Source setup


Shipment tool
Availability testing


Shipment tool
Reliability testing


Shipment tool
Reliability testing


Shipment tool
Ongoing buildup


Shipment tool
Ongoing buildup


Shipment tool
Ongoing buildup

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Source

- Machine is ready for production
- Source has still way to go
- Current source performance is ~>10 W vs required for NXE 3300 of 100-250 W
- Progress is on the way (REFERENCE TO LAST CYMER AND DPP)

- But ….

- We can not stop at 250 W. Yan Borodovsky (Intel): “EUV source power targets need to be revised upwards (≥1kW average in-band @IF) to meet Complementary Lithography and Contacts patterning technology needs” (2012 Lithography Workshop, Williamsburg, VA, USA)

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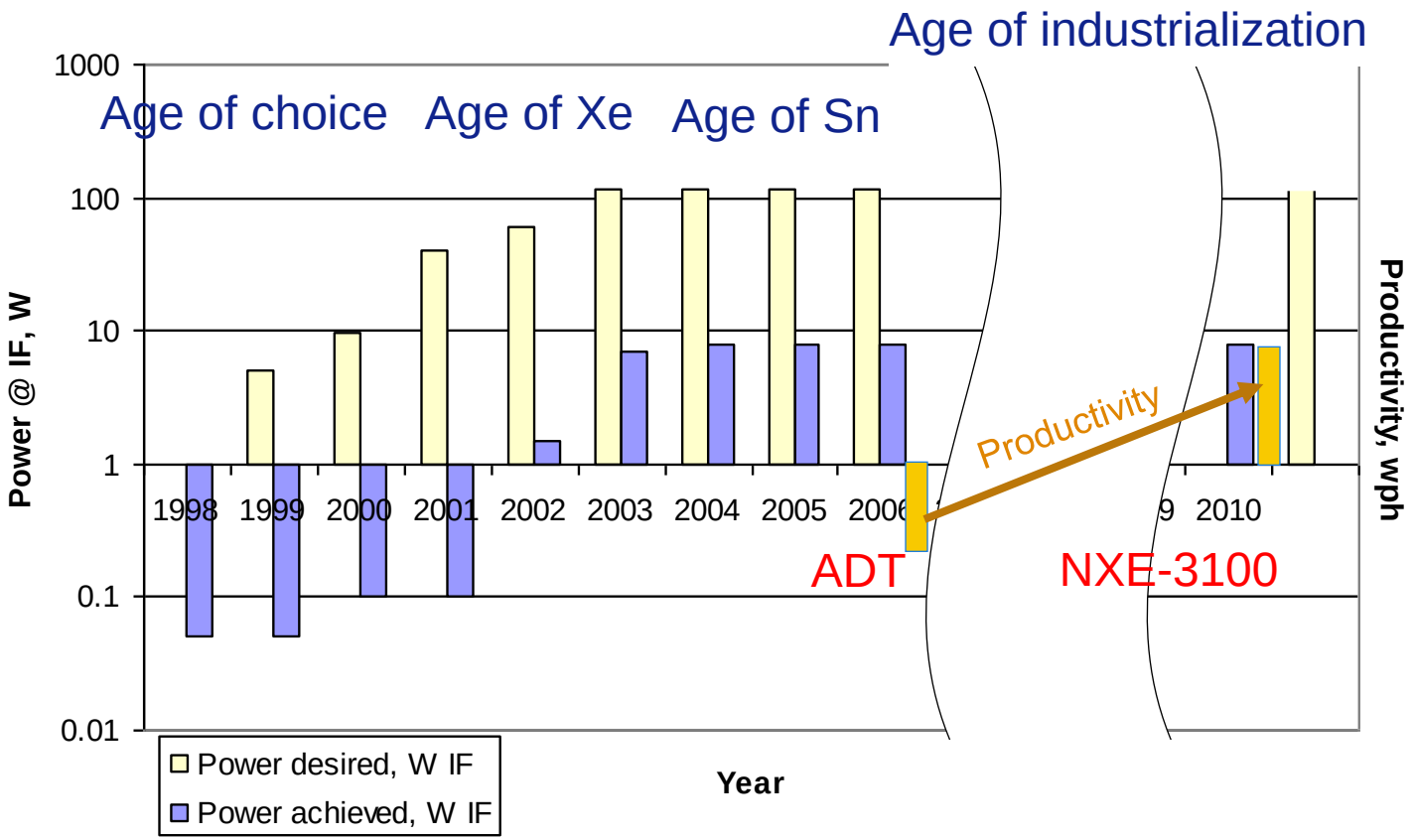
Why increase in the source requirement

- The smaller the CD the higher shot noise impact on CDU and LER the higher resist dose is needed
- Are there ways to improve resist? Possibly:
  - Increase Dill B (from 6->24)
  - Increase mask CD (biasing 1-> 1.2)
  - Increasing aspect ratio of the features (from < 2:1)
- But we are at the source workshop now. Let us try to re-think what we can do to get to

1000 W source

Conventional scaling

Historical perspective on EUV source: Production power requirement, achieved power, productivity



Averaged and independent on supplier

Gap in productivity is being bridged,
in reliable power is still 10x to go.

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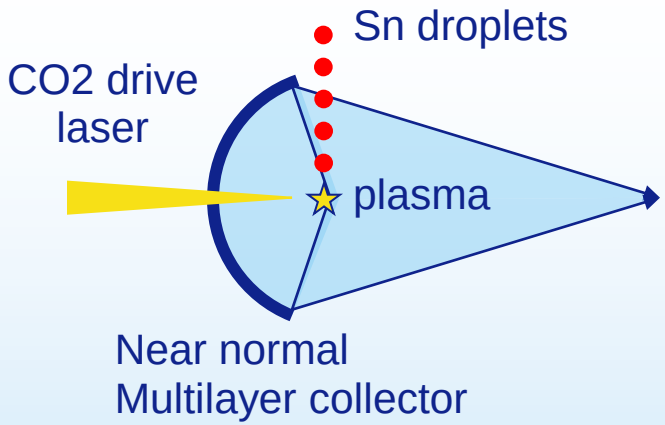
Two EUV source concepts

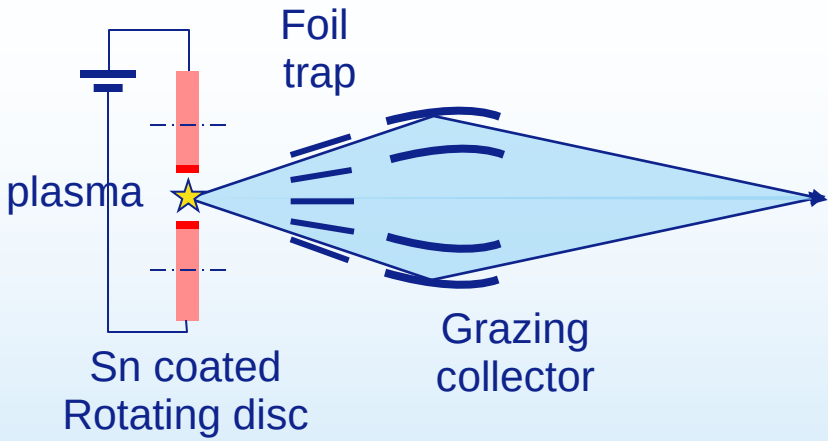
Laser-Produced Plasma (LPP)



- CO_2 laser ignites tin plasma
- Debris mitigation by background gas and possible magnetic field (Giga)

Suppliers: Cymer, Gigaphoton inc.

Electrical Discharge (LDP)



- High voltage ignites tin plasma
- Debris mitigation by foil trap

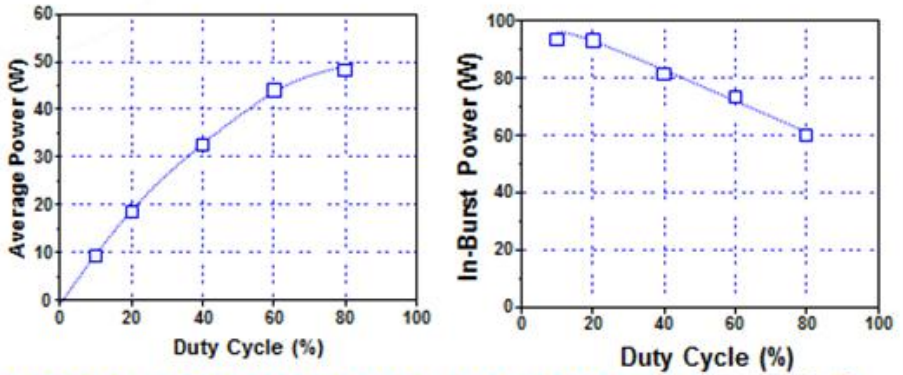
Supplier: XTREME technologies GmbH

Presentations David Brandt (Cymer), Gigaphoton Inc., XTREME technologies GmbH

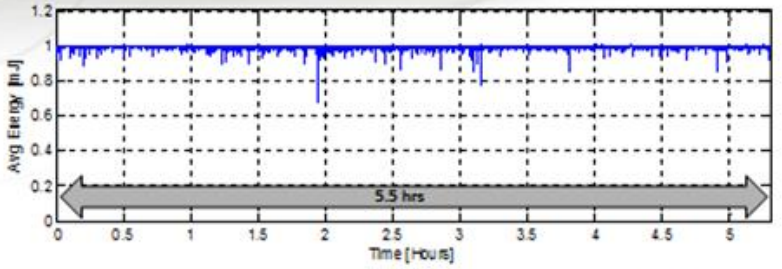
LPP now

LPP with Prepulse: Capability up to ~50W Average Power at High Duty Cycle Demonstrated

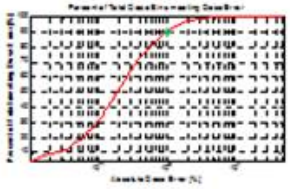
- Prepulse technology demonstrated up to 90W in the burst
- Power roll off (as discussed at SPIE) remains a challenge, new metrology provided learning needed to diagnosis the problem



PrePulse Demonstrated with Closed Loop Control over 5 hours of Continuous Operation



- 50W in-burst dose-controlled power at 40% duty cycle (20W average power)
- Energy, timing, and plasma position under closed loop control
- 90% of die better than <1% dose error



Special thanks to David Brandt

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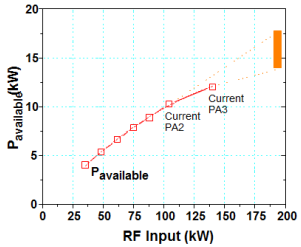
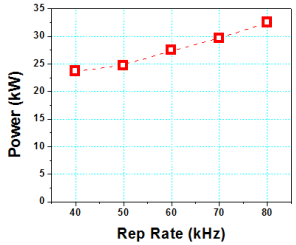
LPP scaling

Power Scaling to 250W using CO_2 Laser Power, Conversion Efficiency and Repetition Rate

	Pilot 7	LT1	HVM II: 70W	HVM II: 125W	HVM II: 160W	HVM II: 250W
EUV in-burst power	40W	140W	70W	125W	160W	250W
EUV average power	32W	5W	70W	125W	160W	250W
Duty Cycle	80%	3%	100%	100%	100%	100%
Drive Laser	17kW	24kW	20kW	31kW	31kW	43kW
CE	1.1%	2.9%	2%	2%	2.5%	3%
Dose Control Margin	35%	NA	30%	20%	20%	20%

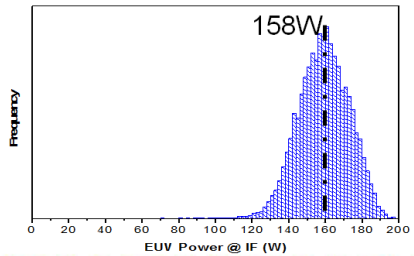


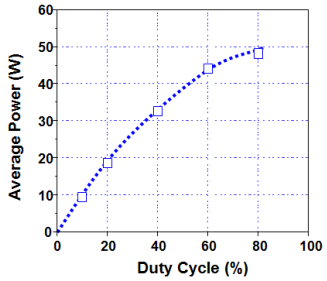


EUV Power Scaling Baseline

Low-Duty-Cycle Demonstration Status (LT1)	
Expose power (calc.)	140W
Raw power (mean)	158W
Raw power	190W
CO_2 power	24kW
Test length	>15min
Duty Cycle	3%

High-Duty-Cycle Demonstration Status (P7)	
Expose power (calc.)	40W
Raw power (mean)	60W
Raw power (peak)	70W
CO_2 power	17kW
Test length	~10min
Duty Cycle	80%





LPP shows potential of scaling in low duty cycle experiments

Special thanks to David Brandt

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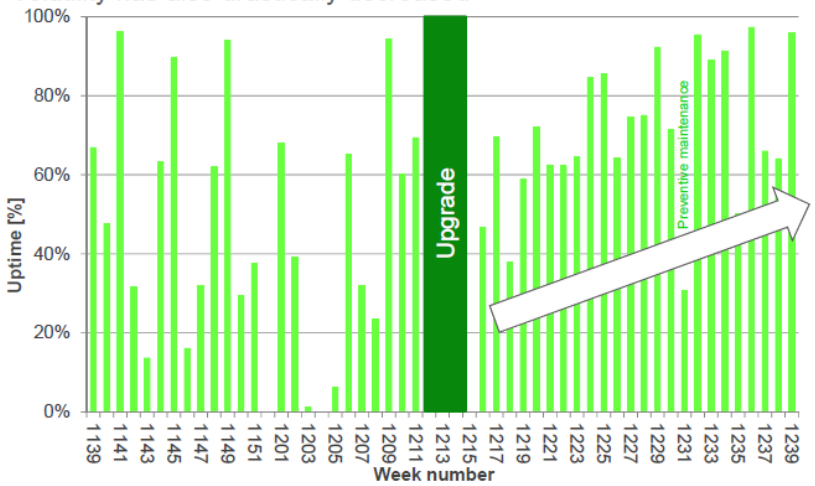
DPP now

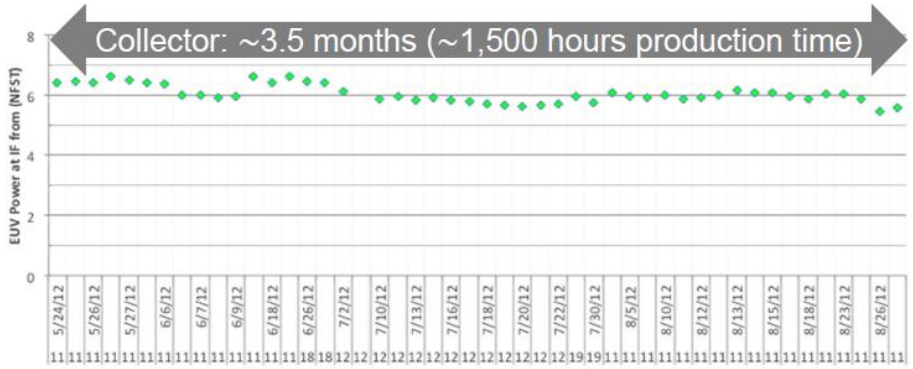
After Upgrade, Ushio 1 Uptime Has Steadily Increased …

- Recently, uptime exceeds 90% (13 wk average now exceeds 75%)
- Volatility has also drastically decreased



Long Collector Lifetime Is Achieved

- Power at IF is stable over the collector life

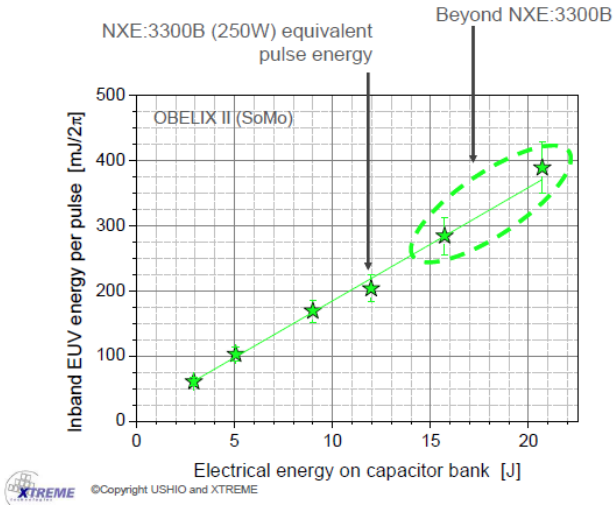


Special thanks to Rolf Apetz

DPP scaling

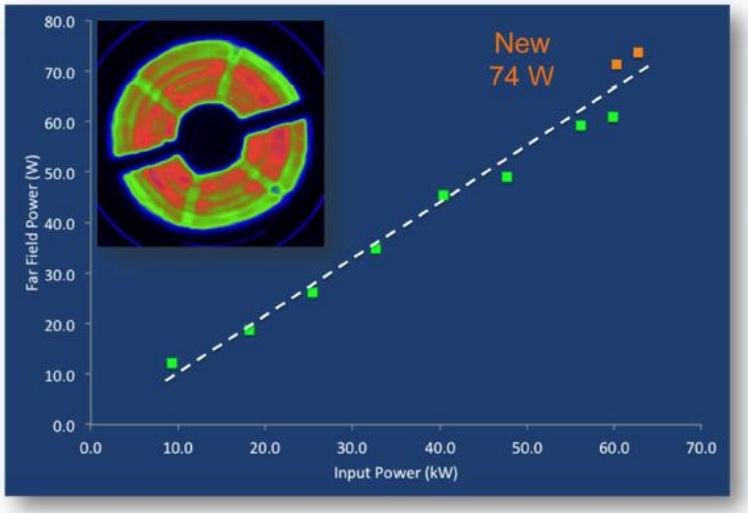
LDP Pulse Energy Scalability

- LDP's long term pulse energy scalability is proven BEYOND the requirements for NXE:3300B (250W)



Just In:

New Record 74 W After IF



Burst mode
200 ms / 12% DC

Pulse energy
3-4 J

1 hour run at 74W

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Please visit Poster P-SO-05
Felix Kuepper, Fraunhofer ILT

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DPP shows potential of scaling in low duty cycle experiments

Special thanks to Rolf Apetz

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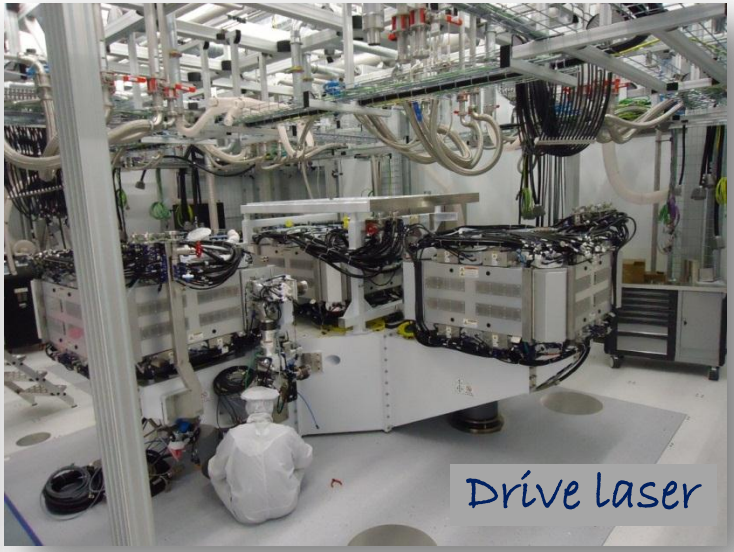
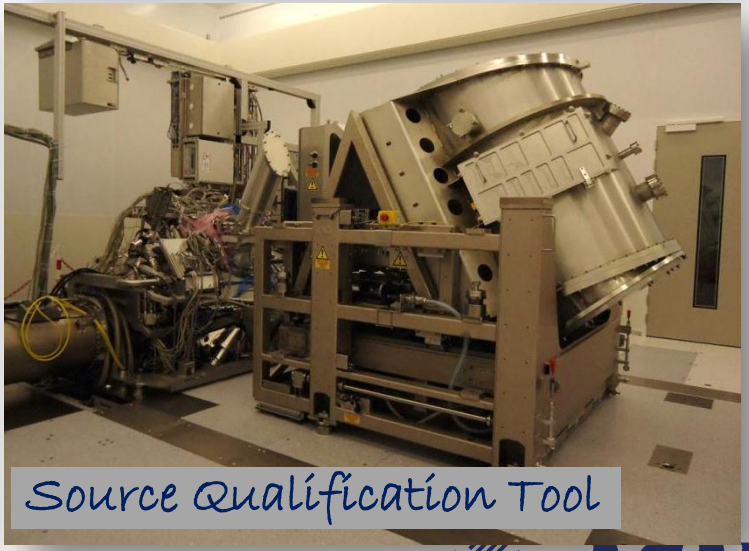
3300 source hardware installing in Veldhoven





Conventional scaling of LPP

- According to Fomenkov et al @ SPIE 2012 :
  - For 185 W EUV 35+ kW laser power is needed @ 3% CE thus
  - For 1000 W (@CE= 3%) -> 190+ kW laser power or
  - For 1000 W (@CE= 5%) -> 110+ kW laser power
- Challenges and question to the conference:
  - CE increase viability at higher powers? (GPI @ SPIE 2012 reported 5%)
  - Laser power scaling or multiplication
  - Maintaining cold gas buffer for lifetime of the mirror at the 3-4x increase of power load
  - Maintaining lifetime of collector at increased (3x-4x) Sn consumption (Is GI collector (Media Lario SPIE 2012) a viable idea in this case?
  - Droplet generator scalability to higher frequencies?
  - ….

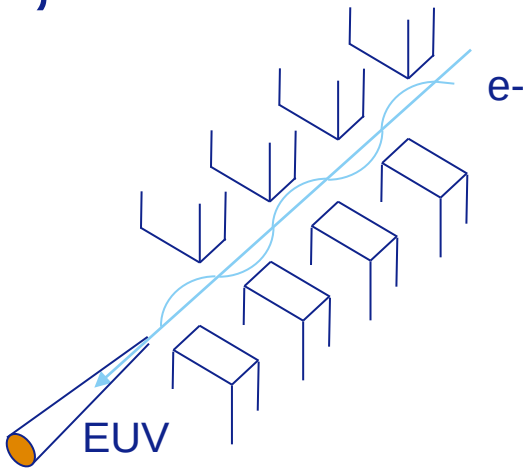
Conventional scaling of DPP (LDP)

- According to Corthout et al @ EUVL symp 2010:
  - For 107 W EUV 76 kW power input is needed @ 2.3% CE thus
  - For 1000 W (@CE= 3%) -> 700+ kW power input is needed
- Challenges and question to the conference:
  - Is CE increase an option?
  - Will discharge heads still work at this power or jets is a way (Koshelev et al SPIE 2012)
  - How to scale foil trap when > ½ MW is dissipated at a short distance (increase the distance -> collector size and track length)
  - ….

Not conventional scaling

Synchrotron wiggler, undulator , FEL

Never made it



Principle:

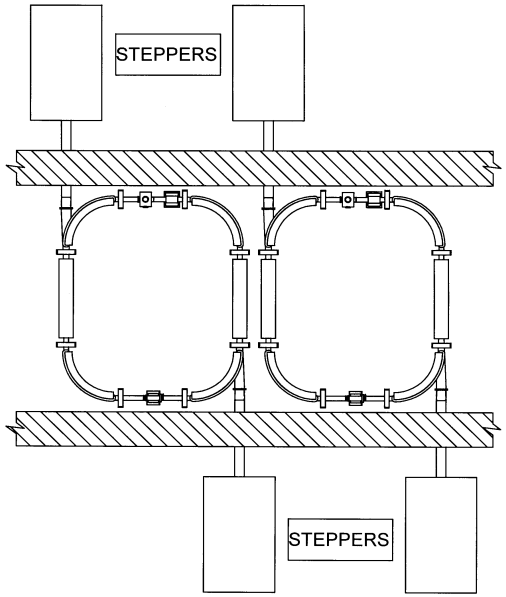
1. Relativistic electrons traversing a periodic magnetic structure are being bent;
2. Being bent, electrons emit EUV.

Prospects before 2000:

1. No debris;
2. Good dose repeatability;
3. High maturity (1999!);
4. High uptime

Issues:

1. High CoO;
2. Non-flexible configuration.
3. Not enough power (2005!)
4. Current update: 0.2 W with FLASH (250 m installation)



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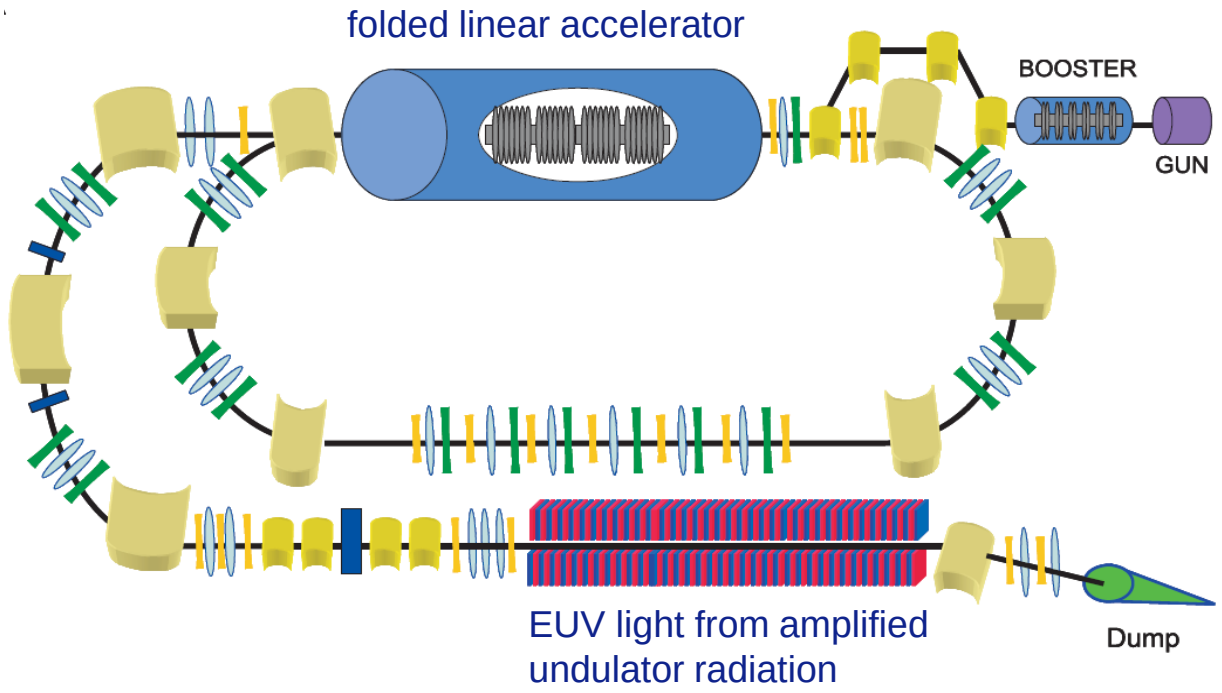
Alternative high power source: free electron laser

EUV radiation from an accelerator based source.



- average power > 1kW
- repetition rate > 250 kHz

Details: Concept Study on an Accelerator based Source for 6.x nm Lithography, Session 11

Looking at the FEL again

- Current update: 0.2 W with FLASH (250 m installation)
- But theoretically … > kW is possible ?

Summary

- The EUVL NXE tool is ready to produce great imaging solutions
- Power of the source has to come still beyond 100+ W and progress is being made as we speak
- 1000 W is needed for the future
- Question to the conference:
- How to do this?

Acknowledgements

The work presented today, is the result of hard work and dedication of teams at ASML, Cymer, Ushio and many technology partners worldwide

Special thanks to David Brandt of Cymer, Rolf Apetz of Xtreme and Diana Tuerke of Zeiss for providing input to this presentation.